Science of the Total Environment 610–611 (2018) 570–575

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Local- and landscape-scale land cover affects microclimate and water use in urban gardens

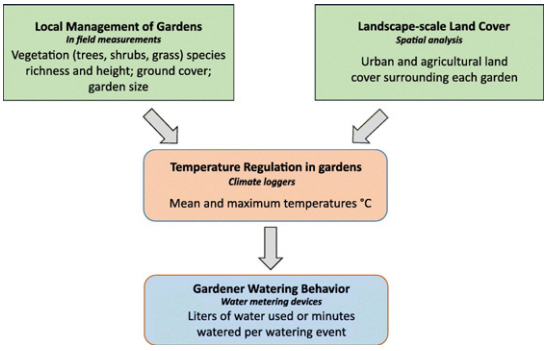
Brenda B. Lin [a,*], Monika H. Egerer [b], Heidi Liere [c], Shalene Jha [d], Peter Bichier [b], Stacy M. Philpott [b]

[a] CSIRO Land and Water Flagship, Australia
[b] Environmental Studies Department, University of California, Santa Cruz, United States
[c] Biology Department, Reed College, United States
[d] Integrative Biology Department, University of Texas at Austin, United States

HIGHLIGHTS

- Extreme temperature and drought affect urban gardens in California, forcing gardeners to ration water supplies.
- Information from all 5 spheres was used to investigate local and landscape factors on garden temperatures and water use.
- Using climate loggers, we examined how vegetation, ground cover, and land cover affect temperature within the gardens.
- Vegetation and ground cover reduced temperatures, while built environment factors increased temperatures. Water use was correlated temperatures.
- Local management of vegetation and ground cover can reduce temperatures and potentially water use in gardens.

GRAPHICAL ABSTRACT


Local Management of Gardens
In field measurements
Vegetation (trees, shrubs, grass) species richness and height; ground cover; garden size
Landscape-scale Land Cover
Spatial analysis
Urban and agricultural land cover surrounding each garden
Temperature Regulation in gardens
Climate loggers
Mean and maximum temperatures °C
Gardener Watering Behavior
Water metering devices
Liters of water used or minutes watered per watering event

ARTICLE INFO

Article history:
Received 28 June 2017
Received in revised form 9 August 2017
Accepted 9 August 2017
Available online 17 August 2017

Editor: D. Barcelo

Keywords:
Urban greening
Climate change
Water use
Groundcover
Land cover
Vegetative complexity

ABSTRACT

Urban gardens in Central California are highly vulnerable to the effects of climate change, experiencing both extended high heat periods as well as water restrictions because of severe drought conditions. This puts these critical community-based food production systems at risk as California is expected to experience increasing weather extremes. In agricultural systems, increased vegetation complexity, such as greater structure or biodiversity, can increase the resilience of food production systems from climate fluctuations. We test this theory in 15 urban gardens across California's Central Coast. Local- and landscape-scale measures of ground, vegetation, and land cover were collected in and around each garden, while climate loggers recorded temperatures in each garden in 30 min increments. Multivariate analyses, using county as a random factor, show that both local- and landscape-scale factors were important. All factors were significant predictors of mean temperature. Tallest vegetation, tree/shrub species richness, grass cover, mulch cover, and landscape level agricultural cover were cooling factors; in contrast, garden size, garden age, rock cover, herbaceous species richness, and landscape level urban cover were warming factors. Results were similar for the maximum temperature analysis except that agriculture land cover and herbaceous species richness were not significant predictors of maximum temperature. Analysis of gardener watering behavior to observed temperatures shows that garden microclimate was significantly related to the number of minutes watered as well as the number of liters of water used per watering event. Thus

* Corresponding author at: CSIRO Land & Water, PMB 1, 107-121 Station Street, Aspendale, VIC 3195, Australia.
E-mail addresses: Brenda.Lin@csiro.au (B.B. Lin), megerer@ucsc.edu (M.H. Egerer), heliere@reed.edu (H. Liere), sjha@austin.utexas.edu (S. Jha), pbichier@ucsc.edu (P. Bichier), sphilpot@ucsc.edu (S.M. Philpott).

http://dx.doi.org/10.1016/j.scitotenv.2017.08.091
0048-9697/Crown Copyright © 2017 Published by Elsevier B.V. All rights reserved.

gardeners seem to respond to garden microclimate in their watering behavior even though this behavior is most probably motivated by a range of other factors such as water regulations and time availability. This research shows that local management of ground cover and vegetation can reduce mean and maximum temperatures in gardens, and the reduced temperatures may influence watering behavior of gardeners.
Crown Copyright © 2017 Published by Elsevier B.V. All rights reserved.

1. Introduction

Urban community gardens (UCG), land set aside for the collective production of food and livestock in urban areas, have experienced a renaissance since the beginning of this century due to their unique environmental, social, and health benefits for urban dwellers (Zezza and Tasciotti, 2010). As such, their role in the urban space is multifunctional (Lovell, 2010; Lin et al., 2015). Environmentally, community gardens can significantly increase biodiversity in urban neighborhoods by providing space for urban greening, but also by allowing a wide range of different species to exist in a single location (Lin et al., 2015). Socially, urban community gardens provide spaces where community members of different cultures, ages, and background can gather over shared interests. This increased social interaction can have benefits for community cohesion and resilience, and for building a space for identity and belonging (Hancock, 2001; Kingsley and Townsend, 2006; Alaimo et al., 2010). Gardens also provide health benefits for gardeners and the local community. Besides increasing food security and the availability of nutritional foods (Alaimo et al., 2008; Guitart et al., 2014), urban gardens provide space for people to connect back to nature and to be physically active (Mckenzie, 2008; Dallimer et al., 2012).

However, there may be challenges faced when conducting outdoor activities within cities. Due to a phenomenon called urban heat island (Oke, 1997), cities register 5–11 °C warmer than surrounding areas (Kalnay and Cai, 2003). Thus, people in urban areas are often exposed to higher heat, and generally for longer periods because the built environment absorbs heat during the day and releases it at night. The urban heat island has been highlighted as a factor in exacerbating several health problems within urban areas including cardiovascular disease and diabetes (Kovats and Hajat, 2008; Luber and McGeehin, 2008). Since gardening, like other outdoor activities, increases people's exposure to extreme weather, especially high heat, it could potentially have negative health impacts (Patz et al., 2005; Tan et al., 2010). Moreover, extreme heat can also affect crop production in gardens, as it does in agricultural systems, thus decreasing yield and harming production levels if plants do not have enough water during high heat periods (Lin, 2011). This may be especially true for gardens that are highly dependent on irrigation (Eriksen-Hamel and Danso, 2010).

Vegetation cover, such as trees, shrubs, and grasses within parks and other urban green spaces can reduce the impact of rising temperatures and heatwaves by providing shade and shelter (Bowler et al., 2010; Gill et al., 2007; Shashua-Bar et al., 2009). Vegetation also has a key role in reducing the amount of solar radiation that is absorbed into building materials such as pavement during the day and released at night (Rizwan et al., 2008). For example, increasing the proportion of tree canopy cover in the urban environment may reduce surface and air temperatures (Gill et al., 2007; Huang et al., 2008). Further, a model of vegetation impacts on future climate change scenarios in Glasgow shows that a 20% increase in green cover could reduce surface temperatures by 2 °C in 2050 (Emmanuel and Loconsole, 2015). However, as with other urban green spaces, the cooling potential in community gardens will depend on the design and management of the system. It is important to understand how effective these shade and shelter effects may be in urban gardens, where people spend large periods of time exposed to the elements and spend large amounts of water to maintain their crops. In this study, we propose to examine how local- and landscape-scale vegetation, ground and land cover affects UCG microclimate in the Central Coast of California.

California presents an important area to study these patterns of land cover and microclimate because California is highly affected by climatic changes that specifically increase the frequency, magnitude, and duration of drought (Mann and Gleick, 2015). Much of the time droughts co-occur with elevated temperatures and heat waves, and the combination of the two climate effects can increase overall drought intensity and heat stress on individuals (AghaKouchak et al., 2014; Mann and Gleick, 2015). Due to this climate cycle and the lack of water storage accumulated through the past decade of drought, water supply reductions have been mandated in California and are expected to become more extreme in the upcoming decades (Pagan et al., 2016). This has led to increased local regulations of water supply that also affect the UCGs, with water restrictions applied by garden managers onto the gardeners (for example, Community Garden Program, 2016).

While increasing climate extremes may put more strain on the community, restrictions of water use may further threaten food production in these systems. Thus, in this study, we examine first, if and how garden management and vegetation characteristics at the local- and landscape-scale are contributing to garden microclimate, and second, if microclimate is predictive of the water use patterns of gardeners.

2. Methods

2.1. Site background

We selected 15 urban community gardens in California across three counties: Monterey (36.2400° N, 121.3100° W), Santa Clara (37.3600° N, 121.9700° W), and Santa Cruz (37.0300° N, 122.0100° W) (Fig. 1).

The gardens represent a spectrum of management systems, with a range of vegetative diversity, structural diversity, and ground management (e.g. mulch, grass cover). The gardens also represent a gradient in landscape heterogeneity, where varying mixes of natural, agricultural, open green space, and urban land cover surround each garden. Gardeners carefully select crops for food, ornamental, and medicinal purposes and manage the groundcover with various organic amendments. The study took place from July to September 2016 during which time, despite a previous wet winter, the region was experiencing a fourth year of drought conditions. More than 80% of land cover within the three studied counties was classified as under drought (Rippey, 2016) and there were state-wide water restrictions in place.

2.2. Collection of climate data

Two temperature loggers (Onset HOBO UA-001-08) were placed in each of the 15 gardens at two locations >10 m apart. They were hung on garden posts and wireframe infrastructures within the gardens based on permissions granted from the gardeners. The loggers were hung at a height of 1.5 to 2 m above the garden beds next to vegetation and were set to record averaged temperature data (°C) every half an hour from July to September 2016.

Data loggers were checked and maintained throughout the survey period to ensure that they were in good working order. Data were downloaded and collected at the end of the survey period and quality checked and cleaned. For each garden, mean and maximum

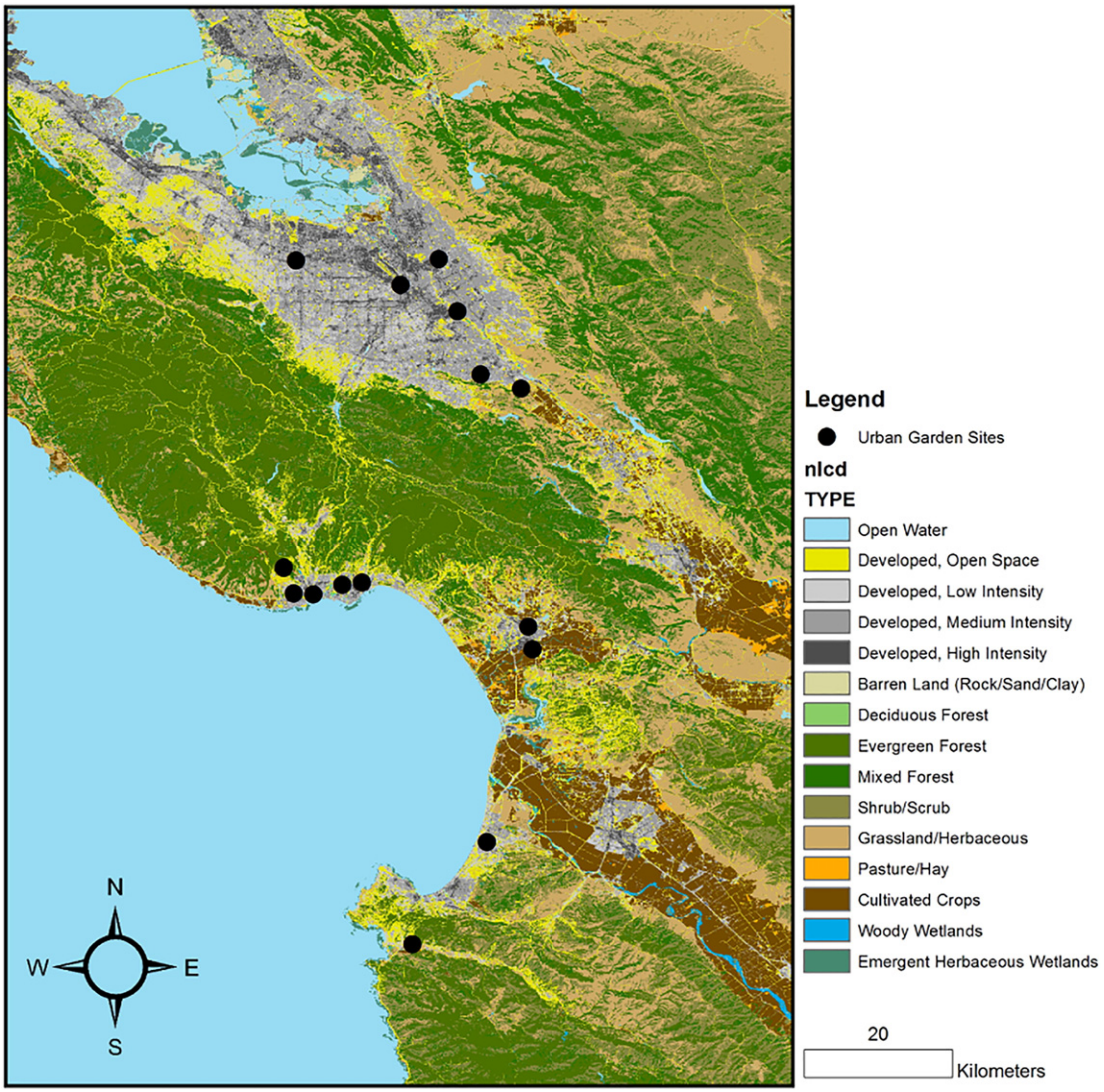


Fig. 1. Location map of the 15 gardens studied within the Central Coast of California. Gardens were located across three counties: Santa Clara, Santa Cruz, and Monterrey Counties.

temperatures were calculated for each day, and an average was calculated throughout the survey period. For the water use analysis, the mean and maximum temperatures were calculated based on the 24 h period immediately before each watering event.

2.3. Collection of local scale garden variables

We established a 20 × 20 m plot at the center of each garden and collected general information (size and age) about the gardens within which we surveyed vegetation and ground cover monthly in eight, randomly chosen 1 × 1 m sub-plots within the larger designated plot. Within each sub-plot, we measured the percent cover and richness of all herbaceous plants (including crops, weeds, and ornamental plants) and the height of tallest herbaceous vegetation. We measured ground cover composition by visually estimating the percentage of bare soil, herbaceous vegetation cover, rocks, leaf litter, and mulch (including woodchips, straw, and other types of mulch cover) within each 1 × 1 m sub-plot. In addition, we counted the number and species of trees and shrubs in the 20 × 20 m plot. Last, we measured canopy cover at five points in each 20 × 20 m plot. We aggregated data at each garden for each sampling period for each site to create a dataset for each garden at each monthly survey period.

2.4. Collection of landscape-scale land cover factors

We collected information on the surrounding landscape composition with data from the 2011 National Land Cover Database (NLCD) (Jin et al., 2013). We created four main land-use categories including: 1) natural land use (combined deciduous forest [NLCD number 41], evergreen forest [42], mixed forest [43], shrub/scrub [52], and grassland/herbaceous [71]); 2) urban land use (combined developed low intensity [22], developed medium intensity [23], and developed high intensity [24]); 3) open land use (developed open space [21]); and 4) agriculture land use (combined pasture/hay [81], and cultivated crops [82]). We assessed landscape composition within buffers surrounding gardens at 2 km. We used spatial statistics tools in ArcGIS (v. 10.1) within each 2 km buffer to calculate the percentage of each land cover type by dividing the area of each type within a buffer by the total area in each buffer (ESRI, 2011).

2.5. Collection of water use data

During the microclimate survey period, we recruited 26 volunteer gardeners at 8 of the garden sites (2–5 per site) to collect information on their water use for 2-week periods in July and September. The gardeners were recruited through garden managers as well as direct

interaction with gardeners during survey periods. Prior to the study, each gardener was provided a summary of the task and asked to fill in a short survey asking them to describe the information they used to decide how long or how much to water.

In order for the gardeners to record their water use, we installed hose faucet water meters (Gardena Brand Electronic Garden Hose Water Meters) at their plots and provided gardeners log books to record the date, time and number of liters used each time they watered over the two weeks. Each watering event was considered a separate data point.

2.6. Analysis

2.6.1. Impacts of local and landscape garden management and vegetation characteristics on garden microclimate

We used a linear mixed-effects model to examine the relationship between local- and landscape-scale characteristics and microclimate measures (mean and maximum temperature) using the maximum likelihood estimate method. We used both the *lme* function in the *lme4* package (Bates et al., 2015) as well as the *Anova* function in the *car* package (Fox et al., 2016) to perform the analysis. Analysis of Deviance Tables were created using Type II Wald chisquare tests based on the *car* package. All analyses were run in R Studio (R Core Team, 2016). We used a Pearson's correlation matrix to determine a set of non-correlated factors to use in the analysis and transformed each factor as needed to ensure that the data was normal. These factors included garden characteristics (garden size, garden age), vegetation characteristics (tallest vegetation height, tree/shrub species richness, herbaceous species richness), ground cover (% cover of grasses, mulch, and rocks), and land cover characteristics (% agriculture cover 2 km buffer, % urban cover 2 km buffer) (Table 1). We included these factors as fixed effects, and we included county (Monterey, Santa Cruz, Santa Clara) as a random effect to account for the regional climatic variation.

2.6.2. Garden microclimate and water use patterns

For the analysis of gardener water use, we determined the effect of daily temperatures on the number of minutes and liters of water that gardeners used at each watering event. We used the mean and maximum temperature (°C) 24 h prior to each watering event in order to focus on the temperature data that would most likely affect the decision-making of gardeners. Generalized linear regression models were built to assess the predictive value of mean and maximum temperature on the number of minutes and liters of water gardeners used per event.

3. Results

3.1.1. Impacts of local and landscape garden management and vegetation characteristics on garden microclimate

Both local- and landscape-scale factors affected UCG microclimates. All factors examined were highly significant ($p < 0.001$) predictors of mean temperature; tallest vegetation, tree/shrub species richness, grass cover, mulch cover, and agricultural landscape cover were cooling factors. Garden size, garden age, rock cover, herbaceous species richness, and urban landscape cover were warming factors (Table 2a). Results were similar for the maximum temperature analysis except that agricultural land cover and herbaceous species richness were not significant predictors of maximum temperature, and rock cover was significant at a $p < 0.05$ level, while the other factors remained significant at a $p < 0.001$ level (Table 2b).

3.1.2. Garden microclimate and water use patterns

Answers from the pre-study survey on the information gardeners used to make their watering decisions (amount of time or water that they used per watering event) showed answers clustered around 'plant needs' (46%), the weather report (21%), and garden rules/management (21%) as the main water use influences.

Analysis of the number of minutes that gardeners watered during the two sample periods showed that both mean temperature and maximum temperature (both from the 24 h before the watering event occurred) were significant predictors for the number of minutes a gardener spent watering their gardens during each watering event (Table 3a, Fig. 2).

Analysis of the number of liters that gardeners used per watering event during the sample periods show that maximum temperature (in the 24 h preceding a watering event) was the primary predictor for the amount of water used at each watering event (Table 3b).

4. Discussion

Urban gardens, as food production and community areas, are important green spaces for individuals to spend time outdoors. However, climate change may create new challenges for these spaces because of increased patterns of drought and extreme heat, two conditions that are highly likely in the Californian Central Coast region. Additionally, increasing urbanization in the region can also affect local- and landscape-scale climatic patterns, resulting in negative human health impacts for urban dwellers (Patz et al., 2005). Interestingly, our study shows that garden management at the local scale may be able to combat regional warming effects through the careful management of local vegetation and ground cover; moreover, our results seem to be predictive of water user behavior within the gardens, suggesting that gardeners may be making decisions on water use based on their perceptions of temperature within the gardens.

Our results show that vegetation cover (tallest vegetation, tree/shrub species richness, grass cover) are significant factors in the cooling of UCG (Table 2a and b). This corroborates urban green space research showing that vegetation cover, such as greater trees, shrubs and grass cover in parks and home gardens, can lower temperatures by providing shade and shelter from solar radiation (Bowler et al., 2010; Gill et al., 2007; Shashua-Bar et al., 2009). Although we found that the cooling effect of trees and shrubs was greater than that of grasses, past studies have shown that grasses are significantly cooler than bare concrete in

Table 1
Fixed effects used within the mixed effect model. Names in the brackets are the shortened names used in the results tables.

Type	Factor	Description
Garden characteristics	Garden size	Size of the urban garden
	Garden age	Number of years garden has been active
Vegetation characteristics	Tallest vegetation (Tallest Veg)	Height of the tallest herbaceous vegetation
	Tree/Shrub species richness (tree/shrub spp.)	Tree and shrub species richness in the entire garden
	Herbaceous plant species richness (HerbPlant spp.)	Herbaceous plant species richness in plots including crop, ornamental, and weed species
Ground cover	% cover of grasses (grass)	Includes all types of grasses
	% cover of mulch (mulch)	includes woodchips, straw, and other types of mulch cover
	% cover of rock (rock)	Includes rocks and concrete
Landscape scale land cover (2 km buffer around garden)	% cover of agricultural land (agricultural 2 km)	Combined pasture/hay, and cultivated crops from NLCD.
	% cover of urban land (urban 2 km)	Combined developed low intensity, developed medium intensity, and developed high intensity from NLCD

Table 2
Local- and landscape-scale impacts on a) mean temperature (AIC = 26.6; BIC = 16.7) and b) maximum temperature (AIC = 56.7; BIC = 66.6). (Significance levels $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$).

a) Mean temperature

Fixed effects	Estimate	Std. error	t-value	Chisq
Garden Size	0.270	0.009	31.69	1004.2***
Garden Age	0.047	0.002	20.03	401.3***
Tallest Veg	−0.018	0.001	−35.19	1238.7***
Tree/shrub spp.	−0.101	0.003	−35.07	1229.8***
HerbPlant spp.	0.007	0.001	5.74	33.0***
Grass	−0.243	0.006	−44.14	1948.0***
Mulch	−0.075	0.001	−79.28	6286.0***
Rock	0.306	0.015	20.68	427.5***
Agricultural 2 km	−0.068	0.007	−9.20	84.5***
Urban 2 km	0.276	0.010	26.90	723.7***

b) Maximum temperature

Fixed effects	Estimate	Std. error	t-value	Chisq
Garden size	1.352	0.363	3.722	13.86***
Garden age	0.286	0.035	8.270	68.39***
Tallest Veg	−0.077	0.017	−4.440	19.72***
Tree/Shrub spp.	−0.290	0.053	−5.437	29.56***
HerbPlant spp.	0.088	0.046	1.929	3.72
Grass	−1.050	0.143	−7.314	53.49***
Mulch	−0.217	0.030	−7.110	50.55***
Rock	1.048	0.430	2.437	5.94*
Agricultural 2 km	−0.231	0.229	1.009	1.02
Urban 2 km	0.896	0.210	4.276	18.28***

cities, and ground surface temperatures cool much faster with grass (Huang et al., 2008); thus, all of these vegetative factors can reduce the urban heat island effect. In areas where tree cover is sparse, the effect of ground cover can be more pronounced, taking on a larger role in influencing the urban microclimate (Lin et al., 2016). For these reasons, policies to increase the level of urban vegetation cover – through both canopy and ground cover - have often been employed to reduce temperatures in high heat zones within cities (Armson et al., 2012; Berry et al., 2013).

Similar increased vegetation strategies have been employed in rural agricultural systems to avoid reduction yield due to extreme temperatures. Many crops are sensitive to changes in temperature and precipitation, especially during flowering and fruit development periods. Temperature extremes can have large effects on crop growth and production. In such situations, vegetation cover is employed to buffer crops from extreme temperatures and extreme weather (Lin, 2010, Tscharntke et al., 2011). For example, in agroforestry systems, structurally complex shade cover can buffer crops from large fluctuations in temperature (Lin, 2007) as well as protect crops from heavy rainfall and winds (Philpott et al., 2008). Ground cover, such as mulches and grasses also buffer crop temperatures and reduce soil surface temperatures (Bowler et al., 2010; Kasirajan and Ngouajio, 2012; Mendoza-Hernández et al., 2014).

Table 3
Result from the multivariate regression examining the relationship between the a) number of minutes watered per watering event and b) number of liters of water used per watering event with the mean and maximum temperatures of the urban gardens (significance levels $^{*}p < 0.05$,$^{**}p < 0.01$,$^{***}p < 0.001$).

a) Number of minutes watered per event

Variable	Estimate	Std. error	t value	*p*-Value
Mean temperature	1.76	0.33	5.4	0.00***
Maximum temperature	0.55	0.27	2.02	0.047*

b) Number of liters watered per event

Variable	Estimate	Std. error	t value	*p*-Value
Mean temperature	−0.25	1.79	−0.14	0.89
Maximum temperature	4.61	1.44	3.21	0.00**

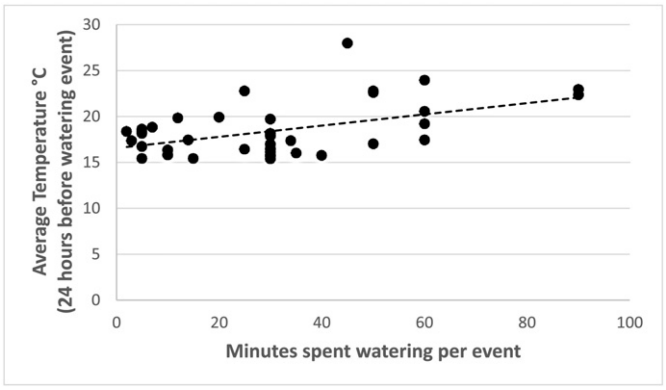


Fig. 2. Minutes spent watering per watering event versus the average temperature (°C) 24 h before the watering event.

Regional-scale studies have shown that urban areas with a higher proportion of built landscape and impervious surface cover can exhibit higher temperatures (Oke, 1997) and can sometimes exacerbate the effect of warming climatic conditions (Patz et al., 2005). These regional patterns support our finding that urban gardens surrounded by a higher percentage of urban land cover exhibited higher within-garden temperatures (Table 2a and b). This is of concern as these gardens are often established in densely populated areas with high levels of built landscape. As gardeners often have little control over the surrounding landscape, the local (within garden) factors that they can manage to increase cooling become critically important.

Interestingly, garden size and age were factors that contributed to increased temperatures within the gardens. Although there were trees present in all gardens, most of them were in the edges of the garden and away from the research plot located at the center, where the climate loggers were placed. Thus, in larger gardens, the distance between the trees and climate loggers was greater, potentially explaining why in larger gardens, the central established plot tended to have higher temperatures than in smaller gardens. Understandably, due to space limitation and/or garden regulations, gardeners do not often grow large shade trees within their plots; however, our results suggest that allocating a centrally located area for trees may be beneficial in terms of reducing temperature and water use, and thus improving growing and gardener working conditions. Many of the older gardens also experienced higher temperatures potentially because the more established gardens were more manicured.

Analysis of gardener watering behavior shows both mean and maximum temperatures were highly correlated with the number of minutes as well as the number of liters of water used per watering event (Table 3a and b). These results indicate that gardeners are sensitive to climate, and that their perceptions of temperature in their gardens can have implication on watering behavior. Educational water and conservation campaigns to change people's behavior for water conservation have often had mixed results on long-term behaviors (Larson et al., 2009; Syme et al., 2000; Warner et al., 2016). Considering the range of motivations for water conservation (Hayden et al., 2015), the results from our study give us an indication of one factor that may be influencing water use behavior, the perception of outdoor local temperature. Other factors, such as rules and regulations for water use, time available to water, and the influence of neighboring gardeners may affect an individual's decisions on watering (Hayden et al., 2015), and we certainly see this coming out in the pre-survey where gardeners indicated that they were also influenced by what they perceived as plant needs as well as garden water management rules. Only 21% of respondents indicated that they were influenced by the weather, although the analysis shows a strong correlation between temperature and length of time and amount watered. Further research to understand the links between watering behavior and motivations for water conservation are required

to tease out these intricate relationships. Even when comparing water use within a household, data constraints have limited the ability of researchers to examine the lawn care-water use link across broad scopes (Milesi et al., 2005), although it is suspected that more than half of a household's water use may be focused on yard irrigation (DeOreo et al., 2016; Kaplan et al., 2014).

4.1. Managing for microclimate and water use

Both landscape- and local-scale management can influence the microclimate of an urban garden. On the landscape scale, increased vegetation cover can affect regional climate patterns by reducing urban heat island effects. Although it is difficult for UCGs to manage for landscape scale factors, understanding the effect land cover has on garden microclimate can assist managers in adopting local management actions to combat regional climate patterns. On the local scale, garden managers can promote within garden vegetation cover or ground cover changes, such as increasing tree canopy cover or grass and much ground cover, to affect garden temperatures,. These actions will benefit gardeners as well as managers by providing a cooler environment that protects human health and crop production. Our research also shows that microclimate may be predictive of water use within these gardens, and in times of drought restrictions and water conservation, management steps to reduce microclimate may assist in water resource management goals.

Acknowledgements

Special thanks to the community gardens for allowing us to conduct research: Beach Flats Community Garden, Berryessa Community Garden, Center for Agroecology and Sustainable Food Systems, Charles Street Garden, Coyote Creek Community Garden, Goodwill Community Garden, Guadelupe Community Garden, La Colina Community Garden, Laguna Seca Community Garden, The Live Oak Grange, MEarth at Carmel Valley Middle School, Mesa Verde Gardens, Pajaro Community Garden, Senior Centre Community Garden, and Trescony Community Garden. Special thanks to many of the gardeners for their participation in collecting water use data. Zach Jordan, Claire Kirk, Dakota Hafalia-Yackel, Ana Rubio, and Mike MacDonald assisted with vegetation data collection. Michelle Otoshi, Jay Tan, and Courtney Arel assisted with landscape analysis. Funding for this project was provided by USDA Grant #2016-67019-25185.

References

AghaKouchak, A., Cheng, L., Mazdiyasni, O., Farahmand, A., 2014. Global warming and changes in risk of concurrent climate extremes: insights from the 2014 California drought. Geophys. Res. Lett. 41 (24), 8847–8852.
Alaimo, K., Packnett, E., Miles, R. a, Kruger, D.J., 2008. Fruit and vegetable intake among urban community gardeners. J. Nutr. Educ. Behav. 40, 94–101.
Alaimo, K., Reischl, T., Allen, J.O., 2010. Community gardening, neighborhood meetings, and social capital. J. Community Psychol. 38, 607–621.
Armson, D., Stringer, P., Ennos, A.R., 2012. The effect of tree shade and grass on surface and globe temperatures in an urban area. Urban For. Urban Green. 11 (3), 245–255.
Bates, D., Maechler, M., Bolker, B., Walker, S., 2015. Fitting linear mixed-effects models using lme4. J. Stat. Softw. 67 (1), 1–48.
Berry, R., Livesley, S.J., Aye, L., 2013. Tree canopy shade impacts on solar irradiance received by building walls and their surface temperature. Build. Environ. 69, 91–100.
Bowler, D.E., Buyung-Ali, L., Knight, T.M., Pullin, A.S., 2010. Urban greening to cool towns and cities: a systematic review of the empirical evidence. Landsc. Urban Plan. 97, 147–155.
Community Gardens Program, 2016. Community Gardens Program 2016 Rules and Regulations. CA, San Jose.
Dallimer, M., Irvine, K.N., Skinner, A.M.J., Davies, Z.G., Rouquette, J.R., Maltby, L.L., Warren, P.H., Armsworth, P.R., Gaston, K.J., 2012. Biodiversity and the feel-good factor: understanding associations between self-reported human well-being and species richness. Bioscience 62, 47–55.
DeOreo, W.B., Mayer, P.W., Dziegieleski, B., Kiefer, J.C., 2016. Residential End Users of Water, Version 2 (Report#4309b). Water Research Foundation, Denver, Colorado.
Emmanuel, R., Loconsole, A., 2015. Green infrastructure as an adaptation approach to tackling urban overheating in the Glasgow Clyde Valley Region, UK. Landsc. Urban Plan. 138, 71–86.
Eriksen-Hamel, N., Danso, G., 2010. Agronomic considerations for urban agriculture in southern cities. Int. J. Agric. Sustain. 8 (1–2), 86–93.
ESRI, 2011. ArcGIS Desktop: Release 10. Environmental Systems Research Institute, Redlands, CA.
Fox, J., Weisberg, S., Adler, D., Bates, D., et al., 2016. Package 'Car'. Companion to Applied Regression. https://cran.r-project.org/web/packages/car/car.pdf.
Gill, S.E., Handley, J.F., Ennos, A.R., Pauleit, S., 2007. Adapting cities for climate change: the role of the green infrastructure. Built Environ. 33, 115–133.
Guitart, D.A., Pickering, C.M., Byrne, J.A., 2014. Color me healthy: food diversity in school community gardens in two rapidly urbanising Australian cities. Health Place 26, 110–117.
Hancock, T., 2001. People, partnerships and human progress: building community capital. Health Promot. Int. 16, 275–280.
Hayden, L., Cadenasso, M.L., Haver, D., Oki, L.R., 2015. Residential landscape aesthetics and water conservation best management practices: homeowner perceptions and preferences. Landsc. Urban Plan. 144, 1–9.
Huang, L., Li, H., Zha, D., Zhu, J., 2008. A fieldwork study on the diurnal changes of urban microclimate in four types of ground cover and urban heat island of Nanjing, China. Build. Environ. 43, 7–17.
Jin, S., Yang, L., Danielson, P., et al., 2013. A comprehensive change detection method for updating the National Land Cover Database to circa 2011. Remote Sens. Environ. 132, 159–175.
Kalnay, E., Cai, M., 2003. Impact of urbanization and land-use change on climate. Nature 423, 528–553.
Kaplan, S., Myint, S.W., Fan, C., Brazel, A.J., 2014. Quantifying outdoor water consumption of urban land use/land cover: sensitivity to drought. Environ. Manag. 53 (4):855–864. http://dx.doi.org/10.1007/s00267-014-0245-7.
Kasirajan, S., Ngouajio, M., 2012. Polyethylene and biodegradable mulches for agricultural applications: a review. Agron. Sustain. Dev. 32, 501–529.
Kingsley, J., Townsend, M., 2006. "Dig In" to social capital: community gardens as mechanisms for growing urban social connectedness. Urban Policy Res. 24, 525–537.
Kovats, R.S., Hajat, S., 2008. Heat stress and public health: a critical review. Annu. Rev. Public Health 29, 41–55.
Larson, K.L., Casagrande, D., Harlan, S.L., Yabiku, S.T., 2009. Residents' yard choices and rationales in a desert city: social priorities, ecological impacts, and decision tradeoffs. Environ. Manag. 44:921–937. http://dx.doi.org/10.1007/s00267-009-9353-1.
Lin, B.B., 2007. Agroforestry management as an adaptive strategy against potential microclimate extremes in coffee agriculture. Agric. For. Meteorol. 144, 85–94.
Lin, B.B., 2011. Resilience in agriculture through crop diversification: adaptive management for environmental change. Bioscience 61 (3), 183–193.
Lin, B.B., Philpott, S.M., Jha, S., 2015. The future of urban agriculture and biodiversity-ecosystem services: challenges and next steps. Basic Appl. Ecol. 16, 189–201.
Lin, B.B., Meyers, J., Beaty, R.M., Barnett, G.B., 2016. Urban green infrastructure impacts on climate regulation Services in Sydney, Australia. Sustain. For. 8 (8), 788.
Lovell, S.T., 2010. Multifunctional urban agriculture for sustainable land use planning in the United States. Sustain. For. 2 (8), 2499–2522.
Luber, G., McGeehin, M., 2008. Climate change and extreme heat events. Am. J. Prev. Med. 35, 429–435.
Mann, M.E., Gleick, P.H., 2015. Climate change and California drought in the 21st century. Proc. Natl. Acad. Sci. 112 (13), 388–3859.
Mckenzie, K., 2008. Urbanization, social capital and mental health. Glob. Soc. Policy 8, 359–377.
Mendoza-Hernández, P.E., Rosete-Rodríguez, A., Sánchez-Coronado, M.E., Orozco, S., Pedrero-López, L., Méndez, I., Orozco-Segovia, A., 2014. Vegetation patches improve the establishment of *Salvia mexicana* seedlings by modifying microclimatic conditions. Int. J. Biometeorol. 58 (5), 853–866.
Milesi, C., Running, S.W., Elvidge, C.D., Dietz, J.B., Tuttle, B.T., Nemani, R.R., 2005. Mapping and modeling the biogeochemical cycling of turf grasses in the United States. Environ. Manag. 36 (3), 426–438.
Oke, T.R., 1997. Urban climates and global environmental change. In: Thompson, R.D., Perry, A.H. (Eds.), Applied Climatology: Principles and Practice. Routledge, New York, NY, USA, pp. 273–287.
Pagan, B., Ashfaq, M., Rastogi, D., Kao, S.C., Naz, B., Mei, R., Kendall, D., Pal, J., 2016, April. Extreme hydrological changes in the Western United States Drive reductions in water supply by Mid Century. EGU General Assembly Conference Abstracts vol. 18, p. 12245.
Patz, J.A., Campbell-Lendrum, D., Holloway, T., Foley, J.A., 2005. Impact of regional climate change on human health. Nature 438 (7066), 310–317.
R Core Team, 2016. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.
Rippey, B., 2016. U.S. Drought Monitor: California. National Drought Mitigation Center.
Rizwan, A.M., Dennis, Y.C.L., Liu, C.H., 2008. A review on the generation, determination and mitigation of Urban Heat Island. J. Environ. Sci. (China) 20, 120–128.
Shashua-Bar, L., Pearlmutter, D., Erell, E., 2009. The cooling efficiency of urban landscape strategies in a hot dry climate. Landsc. Urban Plan. 92, 179–186.
Syme, G.J., Nancarrow, B.E., Seligman, C., 2000. The evaluation of information campaigns to promote voluntary household water conservation. Eval. Rev. 24 (6), 539–578.
Tan, J., Zheng, Y., Tang, X., Guo, C., Li, L., Song, G., Zhen, X., Yuan, D., Kalkstein, A.J., Li, F., Chen, H., 2010. The urban heat island and its impact on heat waves and human health in Shanghai. Int. J. Biometeorol. 54 (1), 75–84.
Tscharntke, T., Clough, Y., Bhagwat, S.A., Buchori, D., Faust, H., Hertel, D., Hölscher, D., Juhrbandt, J., Kessler, M., Perfecto, I., Scherber, C., 2011. Multifunctional shade-tree management in tropical agroforestry landscapes–a review. J. Appl. Ecol. 48 (3), 619–629.
Warner, L.A., Lamm, A.J., Rumble, J.N., Martin, E., Cantrell, R., 2016. Classifying residents who use landscape irrigation: implications for encouraging water conservation behavior. Environ. Manag. 58 (2), 238–253.
Zezza, A., Tasciotti, L., 2010. Urban agriculture, poverty, and food security: empirical evidence from a sample of developing countries. Food Policy 35 (4), 265–273.